Manure Management on U.S. Hog Farms

One consequence of structural change in U.S. hog production has been the manure management challenge posed by concentrating more animals on a limited land base. Hog manure is primarily handled in two types of storage structures, lagoons and pits or tanks (see box, "Manure Storage and Handling Strategies"). Lagoons are large earthen containment structures into which manure and wastewater is flushed and maintained in liquid form until removed. Manure pits are often located under hog production facilities where, in the typical system, manure drops into pits through slatted floors and is stored in a slurry form until removed. These storage structures contain manure until it can be land-applied on the same or nearby farms to meet crop nutrient needs. Technologies for land application include liquid/slurry manure spreaders that may or may not incorporate manure into the soil at application, and sprinkler irrigation systems that are used to spread the liquid lagoon solution on nearby fields.

The different systems for manure management have a vastly different impact on the nutrient content of the manure, primarily nitrogen, and thus on the amount of land needed to spread manure (McBride and Key, 2003). For example, handling manure in pit or tank storage and using slurry spreaders to inject manure into the soil utilizes the manure for its potential fertilizer value. This system is designed to retain manure nitrogen for crop use, and thus requires more land on which to apply manure if following a nitrogen-based nutrient management plan. In contrast, handling manure in lagoon storage and using sprinkler irrigation for spreading treats the manure as waste for disposal, rather than as a source of valuable crop nutrients. This system handles manure to increase the volatilization of nitrogen into the atmosphere, thus reducing its nutrient content and requiring less land for application.

Manure Storage and Handling

Lagoon use and scale of production have a strong positive association (fig. 3). Despite this fact and the trend toward larger operations, there was a shift between 1998 and 2004 toward the use of pit/tank systems. By 2004, 56 percent of hogs were raised on farms using pit/tank systems (up from 37 percent in 1998); in 2004, 39 percent were raised on farms using a lagoon system (down from 55 percent in 1998).[4] This shift can be attributed to changes in the manure system used by medium and large-scale operations, but also reflects regional shifts in hog production and farm structure. Operations in the Southeast more often use lagoon systems, while those in the Heartland are more likely to use a pit/tank system (McBride and Key, 2003). During 1998-2004, hog production expanded in the Heartland relative to the Southeast, as the North Carolina moratorium limited growth in the Southeast.

[4] In tables 2-7, "all farms, weighted by animal units" gives the mean values computed using a weight defined as the sample weight times the animal units on the operation. This weighted mean describes the manure system used for the average animal unit, rather than the average farm.

Pit/tank systems generally use a solid or liquid spreader, while sprinkler irrigation technology is used to move and apply lagoon liquid. The method of applying manure can have important implications for air quality, affecting the level of odorous gases (ammonia and hydrogen sulfide), particulate material (byproducts of ammonia), and greenhouse gases (methane and nitrous oxide) (Abt Associates, 2000). Both solid and liquid manure can be incorporated into the soil, which reduces odor and nutrient volatilization (escape into

Manure Storage and Handling Strategies

Comprehensive nutrient management plan—Following a comprehensive nutrient management plan when applying manure and commercial fertilizer to land can reduce potential losses of nutrients to water resources through runoff or leaching (USDA, NRCS, 2005). Nutrient management matches applications to crop needs so that as few nutrients as possible are lost to the environment. A CNMP is a group of conservation practices and management activities that ensure that both production and natural resource protection goals are achieved. Specific elements of a CNMP include background and site information; manure and wastewater handling and storage; farm safety and security; land treatment practice; soil erosion, nitrogen and phosphorus risk assessment; nutrient management according to criteria in the Nutrient Management Conservation Practice (code 590); and recordkeeping. A CNMP typically includes soil and manure testing for nutrient content, and the balancing of nutrient resources with crop needs. In monitoring the operation's total nutrient balance, the producer must account for nutrients generated, field applied, removed in products, and transferred offsite. Plans can also account for atmospheric losses of nitrogen, as well as atmospheric deposition of nitrogen on cropland.

Manure incorporation and injection—Rapidly incorporating manure into the soil, either by plowing or disking solids after spreading or injecting liquids and slurries directly into the soil, reduces odor and gaseous emissions (Abt, 2000; Arogo et al., 2002). It also reduces the risk of nutrients being transferred to adjacent water bodies.

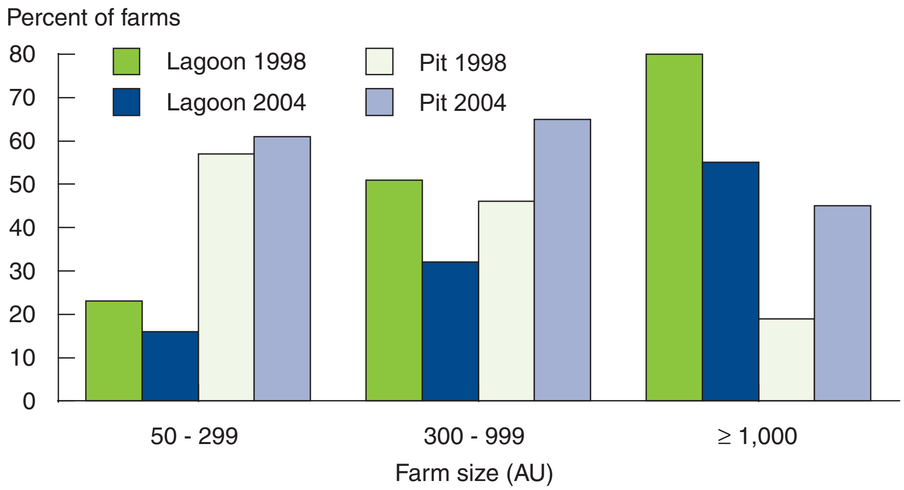
Slurry pits—Slurry systems store undiluted, untreated manure in watertight tanks or pits until it can be land applied. Storage can be either under the house or outdoors. The stored slurry is surface applied to fields by sprayer trucks or wagons, or incorporated into the soil with chisel plows behind nurse tanks, or directly injected into the soil with drag hoses (U.S. EPA, 2004a).

Lagoons—Lagoon systems use open holding ponds to treat diluted manure for an extended period of time. Lagoons stabilize organic matter, reduce the nutrient mass that must be land applied, and vent a large quantity of the manure nitrogen as ammonia. Some of the diluted lagoon liquid is used to flush the production houses. The "digested" lagoon liquid is eventually sprayed on cropland. Lagoons are used primarily in warmer climates where the anaerobic processes can take place year round (U.S. EPA, 2004a).

the atmosphere) relative to spreading, making more nutrients available for plant uptake. Incorporation also reduces the risk of nutrient runoff. Sprinkler application increases nitrogen volatilization, which reduces the nitrogen available for plant use. Lagoon/sprinkler systems allow producers to dispose of manure from a given operation on fewer acres when a nitrogen criterion is used to determine application levels.

There are clear relationships between the scale of production and the use of sprinkler irrigation versus solid or liquid spreaders. Among large farms that

Figure 3
Changes in lagoon and pit manure systems, 1998 to 2004



Source: USDA, ERS, 1998 and 2004 Agricultural Resource Management Surveys.

Table 2
Hog manure application technologies used on farms applying manure

	Percent of farms	
	1998	2004
All farms that apply manure		
Solid spreader	64	46**
Liquid spreader (no injection)	27	18**
Liquid spreader (injection)	20	21
Sprinkler irrigation	12	13
All farms that apply manure, weighted by animal units		
Solid spreader	36	19**
Liquid spreader (no injection)	25	17*
Liquid spreader (injection)	30	34
Sprinkler irrigation	34	36
Farm size category (farms that apply manure)		
Small (50-299 animal units)		
Solid spreader	66	40**
Liquid spreader (no injection)	40	28**
Liquid spreader (injection)	28	31
Sprinkler irrigation	9	10
Medium (300-999 animal units)		
Solid spreader	32	23
Liquid spreader (no injection)	28	19
Liquid spreader (injection)	42	37
Sprinkler irrigation	32	28
Large (≥ 1,000 animal units)		
Solid spreader	10	10
Liquid spreader (no injection)	7	12
Liquid spreader (injection)	20	30
Sprinkler irrigation	58	57

Note: Asterisks indicate level of significance for the test of the null hypothesis of equal means: ** =5%, * = 10%. Some operations may have used more than one technology, or none of the technologies. Therefore, the columns may add up to more than or less than 100 percent.

Source: USDA, ERS, 1998 and 2004 Agricultural Resource Management Surveys.

applied manure to crops, sprinkler irrigation was the most commonly used form of manure application, followed by injection of liquid manure (table 2). Between 1998 and 2004, there was an overall large decline in the share of appliers who spread solid manure. Most of this change occurred because (1) there were fewer smaller farms, which are more likely to handle solid manure, and (2) the remaining small farms less often handled manure in solid form.

Growers altered their spreading technologies between 1998 and 2004 to reduce odor, nutrient volatilization, and runoff. The share of all growers who applied liquid manure without injection declined by 9 percentage points. There was also a 10-percent increase in the share of large operations applying liquid manure with injection technologies, although this increase was not statistically significant.

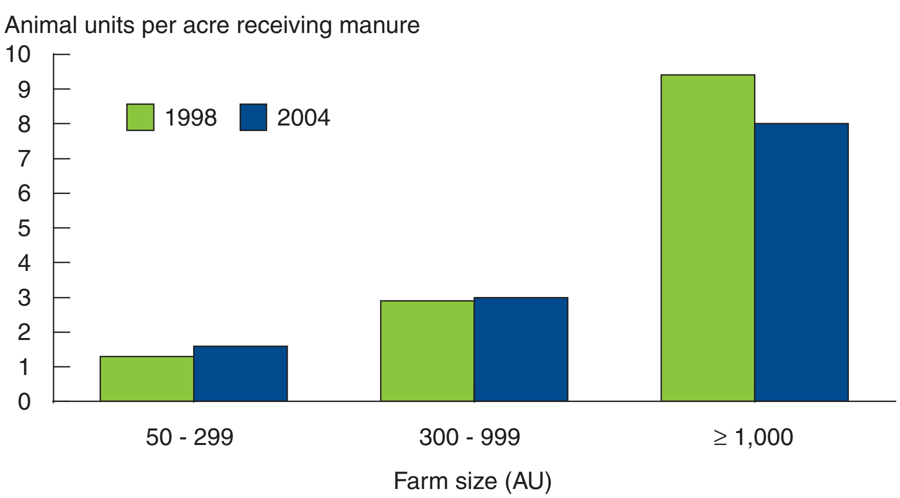
Manure Application and Disposal

There is a strong positive association between scale of production, total cropland available on the hog farm, and the number of acres on which manure is applied on the hog farm (table 3). Between 1998 and 2004, the average number of manure-applied acres and the average amount of cropland per farm did not change substantially. Also, the share of onfarm cropland with manure application remained much the same in 1998 and 2004, and was less than 30 percent among all farms and among farms in each size group. This indicates that the potential exists to spread manure over more crop acreage on these farms. However, higher costs of hauling manure longer distances and the technologies used to spread manure likely limit the acreage on which manure is applied.

Figure 4 illustrates the strong positive association between the scale of production and the manure application intensity (animal units per acre).[5] The higher application rates for larger operations reflect the large amount of manure generated by larger hog operations compared to the cropland on these operations available for manure application. Between 1998 and 2004,

[5] For the intensity ratio, the denominator is the acres of land on the hog operation on which manure was applied. The numerator is the farm inventory (AU) adjusted for the removal of manure off the farm. For farms that moved manure off the operation, the number of AU was reduced by the equivalent amount of manure removed. For example, if 50 percent of the manure was moved off a 1,000-AU operation, only 500 AU was used to compute the ratio.

Figure 4
Manure application intensity increases with scale of production



Source: USDA, ERS, 1998 and 2004 Agricultural Resource Management Surveys.

the increase in total animal units produced outpaced the increase in crop acreage on which manure was applied, resulting in a 43-percent increase in average manure application intensity (table 3). However, this increase was driven mainly by operations with fewer than 300 animal units. For medium-scale operations, the application intensity remained about the same, and for operations with more than 1,000 animal units—which are more likely to be subject to nutrient management restrictions—the application intensity actually declined (fig. 4).

It is important to qualify the measure of manure application intensity. Different storage and handling techniques help determine the quantity of nutrients contained in applied manure, so application intensity does not measure actual nutrient application rates. In addition, increases in feed efficiency have likely reduced the quantity of nutrients excreted by hogs. Nitrogen and phosphorus enter the production system in animal feed. Some of the nutrients are retained in the animal product (meat), but as much as 95 percent is excreted in urine and manure (Follett and Hatfield, 2001). Between 1998 and 2004, feed used per unit of output declined by 24 percent, falling from 282 to 214 pounds of feed per hundredweight gain on feeder-to-finish farms (Key and McBride, 2007). Assuming the nutrient composition of

Table 3
Hog manure application on farms applying manure

	1998	2004
All farms that apply manure		
Acres with manure application	85	86
Acres of cropland	448	483
Percent of cropland with manure application	19.1	17.8
Application intensity (AU/acre applied)	2.1	3.0**
All farms that apply manure, weighted by animal units		
Acres with manure application	147	218**
Acres of cropland	596	855**
Percent of cropland with manure application	24.7	25.5
Application intensity (AU/acre applied)	7.2	7.4
Farm size category (farms that apply manure)		
Small (50-299 animal units)		
Acres with manure application	95	85
Acres of cropland	517	599
Percent of cropland with manure application	18.4	14.2*
Application intensity (AU/acre applied)	1.3	1.6
Medium (300-999 animal units)		
Acres with manure application	156	169
Acres of cropland	565	652
Percent of cropland with manure application	27.6	26.0
Application intensity (AU/acre applied)	2.9	3.0
Large (≥ 1,000 animal units)		
Acres with manure application	159	224
Acres of cropland	643	1,016*
Percent of cropland with manure application	25.0	22.0
Application intensity (AU/acre applied)	9.4	8.0

Note: Asterisks indicate level of significance for the test of the null hypothesis of equal means: ** =5%, * = 10%.

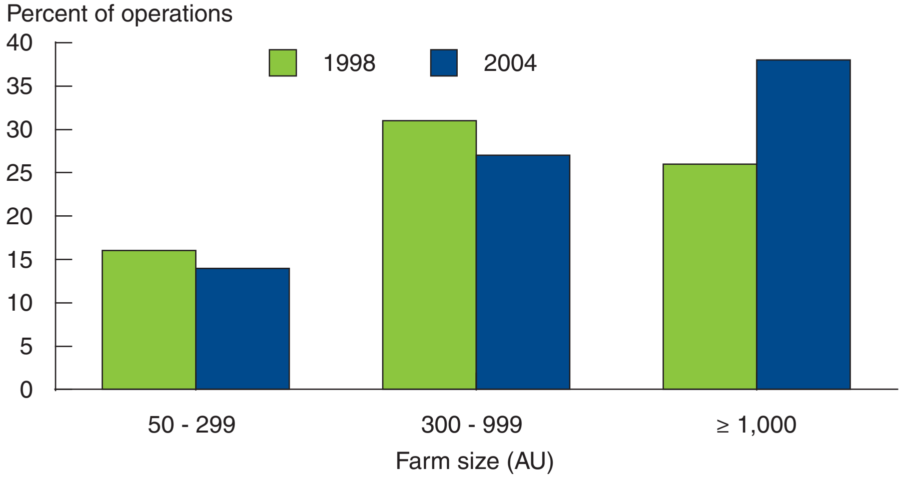
Source: USDA, ERS, 1998 and 2004 Agricultural Resource Management Surveys.

feed and meat has not changed substantially over this period, this implies a 24-percent decline in the quantity of nutrients excreted per animal produced. In addition, feed efficiency is positively correlated with the scale of production—larger operations generally use less feed per hog produced. Hence, the nutrient application intensity (e.g., nitrogen per acre) is generally lower on larger farms than the estimated manure application intensity (animals per acre) would imply.

There is a positive relationship between the scale of production and the quantity of manure removed from farms with hog operations, and this relationship grew stronger over time (fig. 5). The share of farms removing manure grew 50 percent between 1998 and 2004 (table 4), and this increase is attributable mainly to large operations. Manure is most often removed from operations that have limited land for application and can find nearby farms that are willing to make arrangements to have the manure applied to their land.[6] Most of the manure removed from farms was given away to nearby farms—only

[6] Most of the increase between 1998 and 2004 in the share of farms removing manure from the operation occurred on hog operations in the Southeast. Only 3 percent of Southeast operations removed manure in 1998, compared to 18 percent in 2004.

Figure 5
Manure removal from the largest operations increased between 1998 and 2004



Source: USDA, ERS, 1998 and 2004 Agricultural Resource Management Surveys.

Table 4
Manure removal from farms

	Percent	
	1998	2004
All farms		
Removed manure from operation	14	21**
Sold manure	0	2*
Paid for manure removal	2	2
Manure given away free	12	18*
All farms, weighted by animal units		
Removed manure from operation	23	31
Sold manure	1	5
Paid for manure removal	4	4
Manure given away free	19	23

Note: Asterisks indicate level of significance for the test of the null hypothesis of equal means: ** =5%, * = 10%.

Source: USDA, ERS, 1998 and 2004 Agricultural Resource Management Surveys.

a small share was sold or required the operator to pay someone to remove it. There is some evidence of an emerging market for manure—the share of farms selling manure increased in all sales categories between 1998 and 2004, albeit from a very low level.

Manure Nutrient Management Practices

Table 5 describes the evolution of manure management practices between 1998 and 2004. Manure nutrient testing, a practice required as part of many State-mandated manure management plans, was positively associated with scale of production (fig. 6). Larger operations are more likely to face State

Table 5
Nutrient management practices

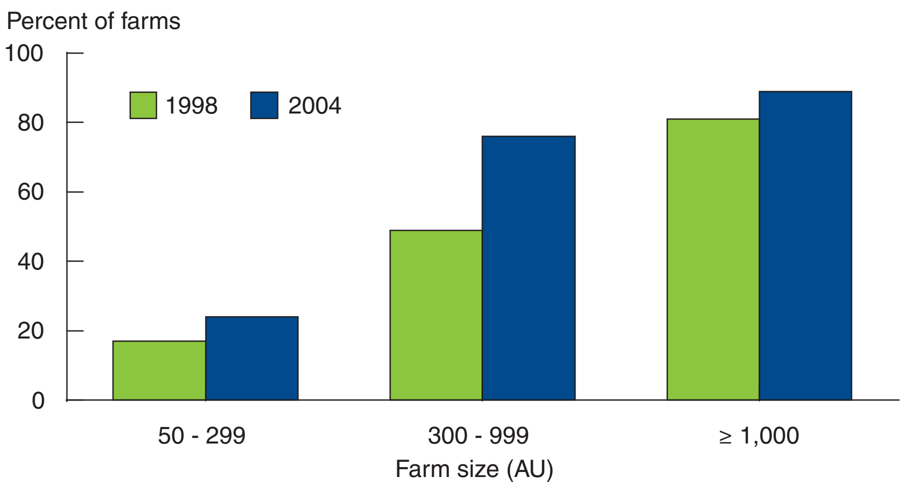
	Percent 1998	Percent 2004
All farms		
Test manure for N content	18	29**
Test manure for P content	17	28**
Apply commercial fertilizer and manure	61	58
Applied manure to Bermuda grass (appliers only)	n.a.	11
Followed CNMP[1]	n.a.	30
Added microbial phytase to feed	4	13**
All farms, weighted by animal units		
Test manure for N content	51	73**
Test manure for P content	50	72**
Apply commercial fertilizer and manure	48	39*
Applied manure to Bermuda grass (appliers only)	n.a.	23
Followed CNMP[1]	n.a.	62
Added microbial phytase to feed	12	30**

Note: Asterisks indicate level of significance for the test of the null hypothesis of equal means: ** =5%, * = 10%. n.a. indicates data not available.

[1] CNMP is a comprehensive nutrient management plan (see box, "Manure Storage and Handling Strategies").

Source: USDA, ERS, 1998 and 2004 Agricultural Resource Management Surveys.

Figure 6
Hog farms increased rate of manure nitrogen (N) testing from 1998 to 2004



Source: USDA, ERS, 1998 and 2004 Agricultural Resource Management Surveys.

regulations that require nutrient management plans. Between 1998 and 2004, the share of farms testing for nitrogen (N) increased from 18 percent to 29 percent, and the share of animals on farms that tested manure for N increased from 51 percent to 73 percent. Nitrogen testing rates increased for all farm-size categories, especially the medium-scale operations (fig. 6). The large operations did not have as much scope to increase their testing rate because 81 percent of these farms tested in 1998.

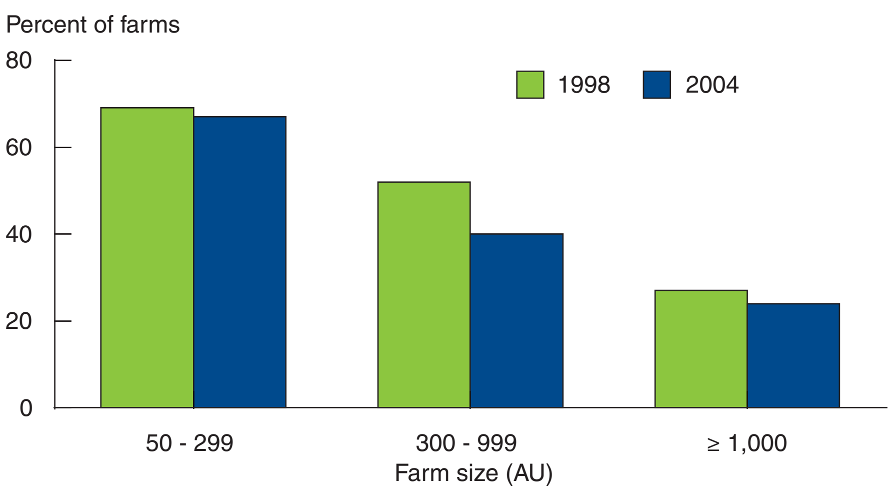
Commercial fertilizer is applied to crops in addition to manure if the manure's nutrients do not meet the nutritional needs of the crops. Testing the nutrient content of manure thus saves costs by avoiding overapplication of supplemental commercial fertilizer. As expected, there is a strong negative association between scale of production and the application of commercial fertilizer (fig. 7). Larger operations are more likely to have a surplus of nutrients provided by the manure produced on their operations, and are therefore less likely to require supplemental commercial fertilizer.

One strategy for increasing manure disposal on a limited land base is to plant crops that have a high rate of nutrient uptake. Bermuda grass, which is grown primarily in the South and Southeast, is especially appealing to hog producers because it consumes large amounts of nitrogen per acre. There was a strong positive association between the scale of production and the application of manure to Bermuda grass in 2004 (fig. 8). However, Bermuda grass will consume soil nutrients only if it is harvested periodically, and there is almost no market for Bermuda grass hay in the areas where it is grown.

Microbial phytase is used as an additive in finishing hog diets to increase the absorption of organic phosphorus, meaning that supplemental inorganic or mineral phosphorus may not be needed and feed costs are reduced. Also, phytase use reduces phosphorus excretion in manure. Lower manure phosphorus content can lead to increased spreading options by reducing the acres required to safely absorb manure nutrients. As expected, there is a positive relationship between scale of production and phytase use (fig. 9). The share

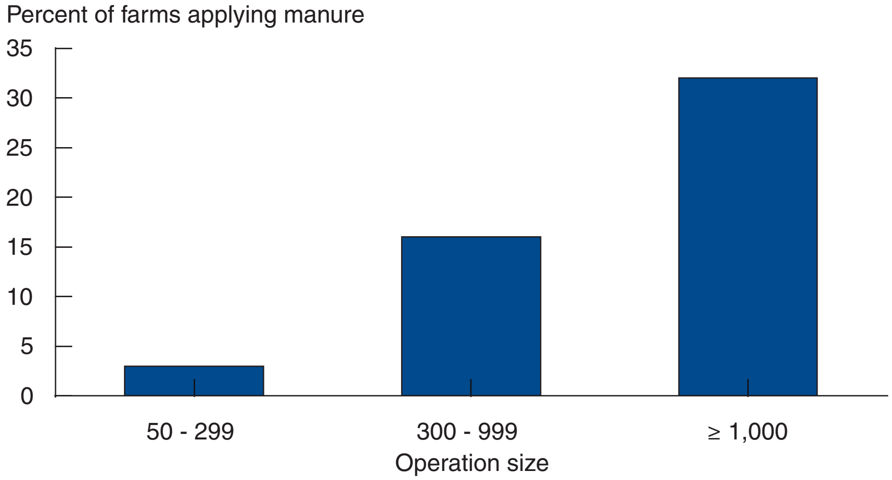
Figure 7

Application of commercial fertilizer with manure declined with size of farm and over time



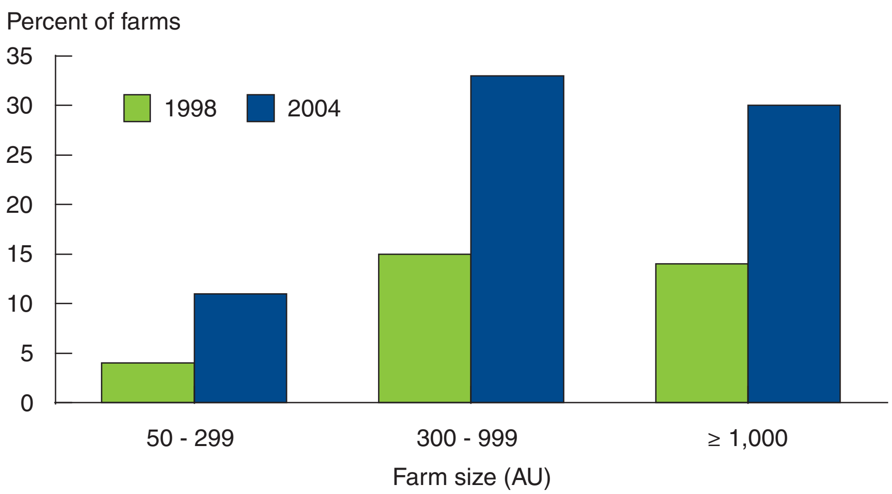
Source: USDA, ERS, 1998 and 2004 Agricultural Resource Management Surveys.

Figure 8
Larger farms are more likely to apply manure to Bermuda grass (2004)



Source: USDA, ERS, 2004 Agricultural Resource Management Survey.

Figure 9
Use of microbial phytase in feed increased between 1998 and 2004



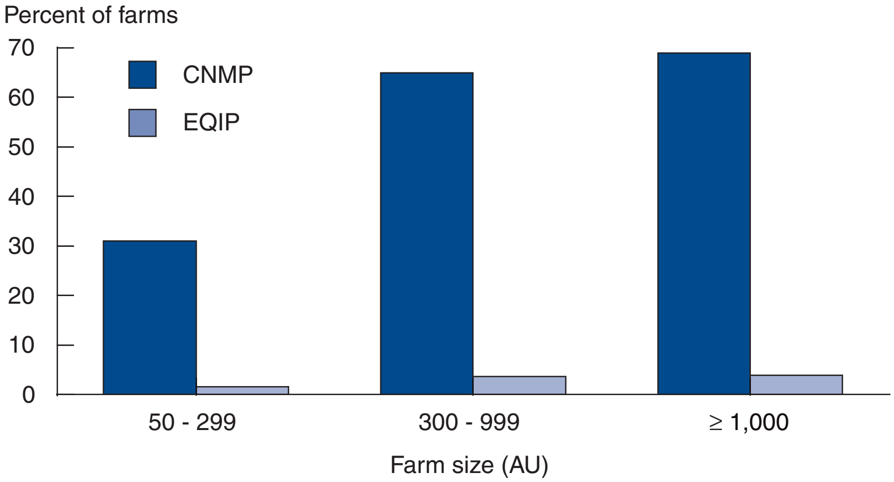
Source: USDA, ERS, 1998 and 2004 Agricultural Resource Management Surveys.

of farms using phytase grew in all size categories between 1998 and 2004, with the share of all farms using phytase more than tripling (from 4 percent to 13 percent). The share of hogs raised on farms using phytase increased from 12 percent to 30 percent. Concern about manure phosphorus levels is also evident from the increase in the share of farms testing manure for phosphorus content between 1998 and 2004 (table 5).

In 2004, about 30 percent of all farms followed a CNMP that requires growers to apply manure nitrogen at or below the agronomic rate and 62 percent of animal units were raised on farms using a CNMP (see box, "Manure Storage and Handling Strategies").[7] There is also a positive association between the scale of production and the use of a CNMP (fig. 10). Only about 30 percent of

[7] The goal of manure application is to apply manure at rates that meet crop needs while avoiding over applications that could lead to water quality impairment. Rates that meet this goal are often called agronomic rates.

Figure 10
Larger farms are more likely to follow a CNMP and receive EQIP payments (2004)



Source: USDA, ERS, 2004 Agricultural Resource Management Survey.

operations with 50-299 animal units followed a CNMP in 2004, compared to more than 60 percent of those with at least 300 animal units.

Environmental Policy and Other Impacts

Recent policy initiatives may explain some of the changes in manure management practices. Federal and State policies implemented in recent years have set limits on the amount of nutrients that can be applied per acre of land. Restricting application rates may explain increases in the crop acreage receiving animal manure and the amount of manure moved off the farm, as well as the widespread adoption of nutrient management plans observed in the ARMS.

Financial assistance from USDA's Environmental Quality Incentives Program helps to defray the costs of meeting the regulations by funding

Table 6
Environmental Quality Incentive Program payments related to hog production, 2004

	Percent
All farms	
Any hog-related EQIP payments	1.5
Manure handling and storage facilities	0.6
Nutrient management plan	0.8
Manure application	0.2
Other[1]	0.4
All farms, weighted by animal units	
Any hog-related EQIP payments	3.2
Manure handling and storage facilities	1.5
Nutrient management plan	2.2
Manure application	0.6
Other[1]	1.1

[1] Includes animal facilities, manure hauling, and unspecified.

Source: USDA, ERS, 2004 Agricultural Resource Management Survey.

planning, installation, maintenance, and technical support for protective conservation practices. Survey results show that only 1.5 percent of farms received any EQIP payments related to hog production in 2004 (table 6). However, 3.7 percent of medium and 3.9 percent of large operations received payments (fig. 10). EQIP payments were used primarily for installing conservation practices associated with manure handling and storage facilities and for developing and maintaining a nutrient management plan. The small share of farms receiving payments in 2004 suggests that these payments do not explain the more widespread changes observed in the study, such as the movement away from lagoons toward pit/tank systems, the decline in the spreading of liquid manure without injection, the increase of manure removal from the operation, the increased use of manure nutrient testing, or the use of microbial phytase in feed. However, these payments may have facilitated these changes, especially for medium and large-scale operations.

Policy initiatives may also explain some of the increased use of such practices as manure injection and development of a nutrient management plan. Agricultural-residential conflicts at the rural-urban fringe may also play a role (Ribaudo and Johansson, 2007). Manure injection reduces odors from land application, and developing a nutrient management plan demonstrates diligence on the part of livestock producers in avoiding harm to the nearby community.